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Extension to AC Loss Minimisation in High Temperature Superconductors

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1. Introduction

In this period of research we concentrated our efforts on AC loss measurements of YBCO coated conductors on textured metallic substrates made in Cambridge. Several samples were prepared by pulsed laser deposition on two different substrates: NiFe and the recently developed NiCrW. The samples differed in sintering conditions and in buffer structures. The two best samples - with the highest critical temperature - on two different substrates were chosen for the AC loss study. The onset critical temperature of both the samples was 85 K, however zero resistance was at about 20 K, i.e. the transitions were very broad. For this reason we decided to perform loss measurements at 5 K using a SQUID magnetometer, since the high frequency equipment will not go down to this temperature.

2. Results

The sample architecture was YBCO/Y_2O_3/CeO_2:Pd/NiFe and YBCO/Y_2O_3/YSZ/CeO_2:Pd/NiCrW. Both samples had a thickness of YBCO of 350 - 370 nm and the buffer structure thickness was 200 nm. The thickness of NiFe and NiCrW substrates was 35 μm and 90 μm, respectively.

The measurements were performed in applied magnetic fields up to ±6 T perpendicular to the broader face of the tapes. The critical current densities determined from magnetisation at 3 T for the sample on NiFe and NiCrW substrates were 6.24 x 10^8 A/m^2 and 1.06 x 10^9 A/m^2 , respectively. Their magnetic field dependence follows the Kim relation $J_c=a/(b+|B|)$. To be able to subtract the loss contribution from the substrates the substrates alone with buffer layers - CeO_2:Pd/NiFe and CeO_2:Pd/NiCrW - which underwent the same heat treatment as the original samples were also measured. Hysteresis losses for 1 cm wide tapes (in Joules per cycle per metre length) are higher in the sample with NiCrW substrate than in that with NiFe in the whole magnetic field region ($\mu_o H_{ext}$=0.01 T - 6 T) roughly by a factor of 2, reflecting the sample $J_c(B)$ dependencies. Also the magnetic field dependence of the losses roughly follows a $(\mu_o H_{ext})^n$ dependence with $n\leq 1$. These facts indicate that both samples are in fully penetrated states, even at the lowest applied magnetic fields ($\mu_o H_{ext}$=0.01 T). (In a partially penetrated state the losses would follow $(\mu_o H_{ext})^n$ with n=4 if the $J_c(B)$ dependence follows the Kim relation, and would be approximately inversely proportional to J_c).

An YBCO layer of the sample on the NiCrW substrate was then cut to form 2 filaments and measured again in a perpendicular magnetic field as well as in a field at an angle of 45^o with respect to the tape face. In a perpendicular magnetic field the hysteresis losses of 2 filaments were a factor of about 0.6 lower than the losses of the original single filament, so subdivision is indeed a practical technique for reducing losses. The losses at 45^o roughly scaled as cos(45^o) indicating that the component of the magnetic field perpendicular to the tape face dominates the losses as expected from theory.

The influence on the magnetisation of dividing a monocore tape into 2 and 4 filaments was numerically modelled using the critical state model with a constant critical current density. For full penetration and a perpendicular magnetic field the magnetisation decreases proportionally with increasing number of filaments. However, due to the high aspect ratio of the tape, there is no visible effect in a parallel magnetic field. Hysteresis losses in metallic

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substrates - CeO_2:Pd/NiFe and CeO_2:Pd/NiCrW - were substantially lower than the total losses of the composite tapes. The losses in NiFe substrate at $\mu_o H_{ext}$=3 T (perpendicular to the tape face) were more than 1 order of magnitude lower than the total losses of the composite tape and those in NiCrW were lower by more than 4 orders of magnitude. Magnetisation characteristics of the substrates were measured also at T= 77.3 K and T=100 K. It was found that the magnetisation of the NiFe substrate does not depend on temperature in this temperature range. On the other hand the magnetisation of NiCrW substrate decreases with increasing temperature and becomes small at T=77.3 K (about 40 times lower than that of NiFe).

The main conclusions which can be drawn from these experiments are the following. It was shown experimentally that dividing a tape into filaments reduces ac losses in perpendicular magnetic field roughly in proportion to the number of filaments. The losses in both NiFe and NiCrW substrates are substantially lower than those in the composite tape, however the losses in NiCrW are much lower than those in NiFe.

3. Magnet Screening

Besides the possibility of a significant AC loss reduction by a magnetic screening of the external magnetic field up to about 0.5 T mentioned in our previous report, we would like to draw attention also to a similar possibility in self-magnetic field. The principles were established before the contract started and reported in ref .1. However we have recently been investigating the application of the method to the particular range of parameters likely to be met in motors. Using ferromagnetic sheets as shown in Fig. 1 there is a possibility of self-field loss reduction of more than a factor of three.

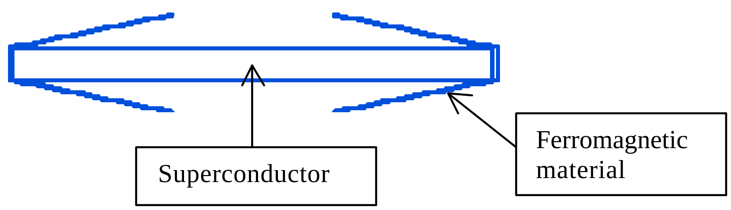

Fig. 1: a) Geometry of the superconducting tape and the ferromagnetic sheets.

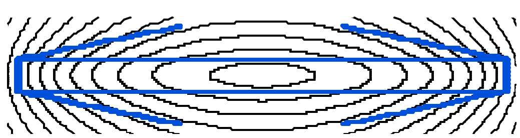

Fig. 1: b) Magnetic field lines (scale 10^{-5} Wb) of a current-carrying conductor (current density 10^9A/m^2) when the relative magnetic permeability of the ferromagnetic material μ_r =1.

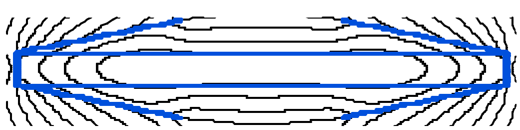

Fig. 1: c) Magnetic field lines (scale 10^{-5} Wb) of a current-carrying conductor (current density 10^9A/m^2) when the relative magnetic permeability of the ferromagnetic material μ_r =60. The transport AC loss decreases more than 3 times.

The simulation was made using the Finite Element Method with the following parameters:-

Superconducting tape 3mm wide and 0.2mm thick, the thickness of the ferromagnetic sheets 6μm, their length 1 mm and the angle with the surface of the tape 11.5°. Numerical simulations were made using the critical state model with J_c=const. The scale of the magnetic field lines in Fig. 1b and Fig. 1c is the same so a direct comparison of the figures is possible. The presence of the ferromagnetic sheets decreases the magnetic field in the superconductor and consequently the losses. The AC loss is more than 3 times lower than in a tape without the ferromagnetic sheets.

The publications that occurred in the report period are referenced in the list of publications. Publication [1] reflects our final results on a possibility of achieving a higher critical temperature in MgB_2 material. Publication [2] will summarise the results outlined in the present report.

4. Future Work

Our future research will be concentrated on AC loss measurements on samples of higher quality developed at Wright Patterson Airforce Base. These will be carried out in the fields and at frequencies relevant to motors and generators. We will continue to develop theoretical model for ac loss calculation in coated conductors and analysis of their cryogenic stability.

List of publications:-

1) 1) M. Majoros, B. A. Glowacki, M. E. Vickers, 50K anomalies in superconducting MgB_2 wires in copper and silver tubes. *Supercond. Sci. Technol. 15 (2002) 269.*

2) M. Majoros, R. I. Tomov, B. A. Glowacki, C. E. Oberley, A. M. Campbell, Hysteresis losses in YBCO coated conductors on textured metallic substrates. *Abstract Submitted to Applied Superconductivity Conference, Houston, TX, USA, 4 - 9 August, 2002.*

3) M. Majoros, B. A. Glowacki, Studies of High Temperature Superconductors, Vol. 33, AC Losses and Flux Pinning and Formation of Stripe Phase (ed. A. Narlikar) (2000) p. 1 – 51, (This work predates the contract reported on).